Propulsion Trades for Space Science Missions

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Abstract

Results are presented of a study to evaluate the relative benefits and costs of proposed deep space propulsion technology improvements and recommend an investment strategy. For convenience, three technology readiness time periods were delineated: current (present - 1999), mid-term (2000 - 2004), and far term (2005+). Three technology areas were identified as the key candidates for the primary propulsion role in future deep space missions: advanced chemical, solar electric, and solar sail. Within these areas, the relevant development steps for each time period were defined with the assistance of the technology community.

The current technology baselines used were an NTO/hydrazine system with an Isp = 325 s, the NSTAR solar electric system scheduled to fly on the Deep Space 1 mission, and a solar sail with a 20 g/m2 loading. The latter state was used for discussion purposes only, since the solar sail technology is not expected to be developed until at least the mid-term timeframe. Mid-term technologies examined were a LOX/hydrazine chemical system with an Isp = 350s, the NSTAR improvements planned for demonstration on the Deep Space 4 mission, a quarter-scale (14 cm) NSTAR-derived solar electric system, and a solar sail with a 10 g/m2 loading. Finally, the far term technologies studied were a fluorine/hydrazine chemical system with an Isp = 390 s, a direct-drive thruster with anode layer (TAL) solar electric system (a.k.a. Hall thruster), and a solar sail with a 5 g/m2 loading.

In the evaluations, the figures of merit used were net spacecraft mass delivered, launch vehicle size, trip time, cost, and risk. As defined, net spacecraft mass did not include the propulsion system hardware or accompanying structure. Launch vehicles larger than an Atlas 2AS/Star 48B were not considered. Performance estimates in terms of these figures of merit were compared among the different areas and time frames for a variety of deep space missions. Costs were estimated for incremental technology development, flight systems (first unit and recurring), and operations increases.

The missions chosen for review represent a cross section of type (sample return/lander/orbiter/flyby) and target (planets/moons/sun), with emphasis on those identified in the Space Science Strategic Plan. For a few of the missions, such as the solar polar imager, advanced technology developments are enabling. However, for most of the missions reviewed, there is a trade off between the performance enhancements and the cost. The study found:

- Improvements in chemical ascent propulsion systems are enabling for Mars Sample Return. Other advanced chemical systems provide some performance enhancements for several missions, but at a very high development cost.

- The mid-term solar electric systems give substantial benefits for moderate development costs, while the far term system yields moderate additional benefits for only a small number of missions.

- The far term solar sail capability enables or significantly enhances several missions. Mid-term sail capability enables a couple of missions and serves as a stepping stone for the far term capability. Development and unit cost estimates were relatively low albeit with more uncertainty than the others.

Based on these findings, the recommended investment strategy gives priority to mid-term solar electric propulsion systems, ascent propulsion systems for a Mars sample return mission, and the first steps toward solar sail capability.